SPECIAL REPORT

# EFFECTS OF MUDSEAL SLOT DETERIORATION ON DISCHARGE THROUGH SPILLWAY STRUCTURES S-70 AND S-75


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## EXECUTIVE SUMMARY

Structures S-70 and S-75 are gated spillways with mudseals. The discharge through these structures should be independent of the gate opening for openings in the range of 0.125 to 0.5 feet. However, experience has shown that the discharge increases with increasing gate openings for all gate openings. A deterioration of the concrete slot resulting in a v-notch cross-section could explain the observed behavior.

Verification of the proposed geometry is difficult. Verification cannot be obtained by underwater diving because of the dangers involved in opening the gate far enough to observe the slot conditions. Stream gauging is not accurate at the low flow rates in question. Experience justifies incorporating a variable discharge but quantifying the change is extremely difficult. The proposed v-notch geometry resulting from the deterioration of the original slot appears to represent the best solution to account for the observed varying discharge.

The equations that are currently used to compute the discharge through structures S-70 and S-75, as well as the changes to the equations in light of the above described new conditions, are presented.

**ABSTRACT**

The discharges at District control structures S-70 and S-75 have been known to increase with increasing spillway gate opening for gate openings in the range of 0.125 to 0.5 feet. Accepted theory indicates that these mudseal structures should have a constant discharge for gate openings in this range. A v-notch slot geometry, representing slot deterioration, is proposed to account for the observed behavior. A solution in the form of a general equation is offered. Results are compared for the design and proposed geometries.

**Key Words.** spillway, mudseal, discharge.

## CONTENTS

## ACKNOWLEDGMENTS

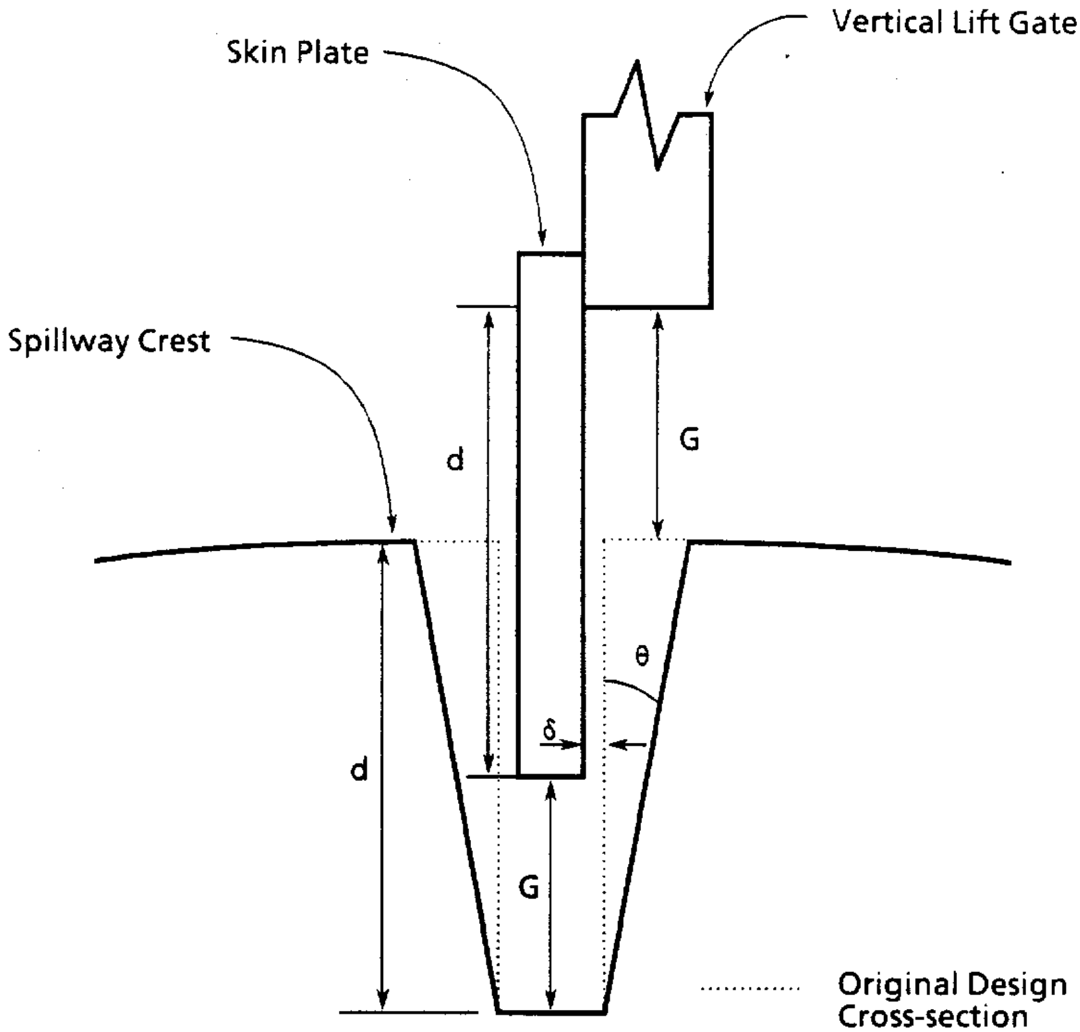
George Hwa of Resource Operations Department, Operations Division, informed Data Management Division of the phenomenon in question. Ron Mierau of the Resource Planning Department, Data Management Division, offered the proposed solution. Carol Goff typed the manuscript.

## INTRODUCTION

A scrutiny of the gate openings and the resulting stage data for spillway structures S-70 and S-75 revealed that the discharge tended to increase with increasing gate openings in a range for which theory would indicate a constant flow value. These two structures are located in the Indian Prairie Basin in which the District and Seminole Tribe will, in the near future, sign a water allocation Compact Agreement (see Operations Division's memorandum in the Appendix). The sensitive nature of such an agreement required that the procedure used to compute the discharge at the two stations, S-70 and S-75, be reviewed for accuracy and for purposes of determining the cause of the anomalous behavior.

Structure S-70 is located on Canal 41 about 10.5 miles upstream from Lake Okeechobee and Structure S-75 is located on Canal 40 about 14 miles upstream from Lake Okeechobee. Each structure was designed to: (1) maintain optimum water control stages in its respective canal; (2) pass the design flood without exceeding the upstream flood design stage while simultaneously restricting downstream flood stages and channel velocities to non-damaging levels; and (3) pass sufficient discharge during low-flow periods to maintain downstream stages and irrigation demands.

Both Structures S-70 and S-75 are reinforced concrete spillways. Discharge is controlled by vertical lift gates to which are attached mudseals which extend 0.5 feet below the rubber seals on the upstream side of the crest. The mudseal skin plates form a 0.125-foot gap with the vertical slot faces on either side. The gap effectively becomes the constant gate opening in the gate-opening range of 0.125 to 0.5 foot. However, recent observations have shown the discharge to increase with gate openings in this range. This anomalous behavior has led to the conclusion that the concrete slot that houses the mudseal may have deteriorated over time, resulting in a much wider gap between the mudseal and each of the originally vertical slot faces. It is based on this conclusion that new discharge equations are proposed. The new equations are based on the assumption that the current slot faces are slanted due to greater concrete spalling near the slot opening than the bottom of the slot; that is, a v-notch cross-section would appear to adequately account for the observed variable discharge in the gate opening range of 0.125 to 0.5 foot. Unfortunately, this assumption cannot be verified by physical examination by a diver because of the potential dangers inherent in such an undertaking. The assumed cross-section is depicted in Figure 1.




G = gate opening
δ = gap between skin plate and assumed vertical slot face
θ = angle of deterioration (assumed symmetrical)
d = depth of mudseal slot ≈ length of mudseal skin plate

Figure 1. Definition Diagram

## FLOW EQUATIONS FOR THE STRUCTURES

The gate-controlled discharge through the S-70 and S-75 spillway structures is currently computed using the following equation:

$$Q = C_D\, B\, G_e\, (2\, gh)^{1/2}$$

in which:

| | | |
|---|---|---|
| $C_D$ | = | discharge coefficient; |
| $B$ | = | width of opening; |
| $G_e$ | = | effective gate opening; |
| $g$ | = | gravitational acceleration; |
| $h$ | = | head across the structure. |

For submerged flow:

$$h = US - DS$$

in which:

| | | |
|---|---|---|
| US | = | upstream water elevation; |
| DS | = | downstream water elevation. |

For free flow:

$$h = US - SILL - 0.5\, G_e$$

in which:

| | | |
|---|---|---|
| SILL | = | sill elevation. |

**The effective gate opening governs discharge and is defined as the minimum distance between the gate and slot, for a given gate opening.**

**The effective gate opening, $G_e$, is determined as follows:**

$$G_e = \begin{cases} G, & \text{for } 0 \leqq G \leqq \delta \\ \delta, & \text{for } \delta < G \leqq d \\ [(G-d)^2 + \delta^2]^{1/2}, & \text{for } G > d \end{cases}$$

in which:

$G$ = actual gate opening (measured vertically);

$\delta$ = gap between the mudseal skin plate and the slot face (assumed vertical);

$d$ = depth of the mudseal slot $\approx$ length of mudseal skin plate.

The values of $\delta$ and d are 0.125 ft and 0.5 ft respectively for both structures S-70 and S-75. Therefore, the discharge through these structures would be expected to be constant for gate openings in the range of 0.125 to 0.5 ft. However, as mentioned previously, the discharge has been observed to increase with gate opening in this range, suggesting that the concrete slot may have experienced some deterioration resulting in a much wider gap between the mudseal and the slot face.

## NEW EQUATION FOR EFFECTIVE GATE OPENING

The spalling of the concrete in the mudseal slot has probably resulted in a slot geometry for which the effective gate opening equation given above is no longer applicable. A fairly reasonable assumption in the manner in which spalling may have occurred leads one to propose a v-notch cross-section as shown in Figure 1. With the proposed v-notch cross-section, the equation for effective gate opening assumes the following form (refer to Figures 2, 3, and 4):

$$G_e = \begin{cases} G, & \text{for } 0 \leqq G \leqq \gamma_1 \\ \delta\cos\theta + G\sin\theta, & \text{for } \gamma_1 < G \leqq \gamma_2 \\ [(G-d)^2 + (\delta + d\tan\theta)^2]^{1/2}, & \text{for } G > \gamma_2 \end{cases}$$

in which:

$\gamma_1$ is the value of the vertical gate opening, G, for which the $G_1$ is equal to the distance from the gate to the slot face (see Figure 2). The gate opening is thus given by:

$\gamma_1 \quad = \delta\cos\theta/(1-\sin\theta)$

The computation of the effective gate opening, $G_e$, changes at two values of the gate opening, G. The two values are represented as $\gamma_1$ and $\gamma_2$ where $\gamma_1 < \gamma_2$:

$$\gamma_1 = \delta\cos\theta + \gamma_1\sin\theta$$

$$= \delta\cos\theta \ / (1-\sin\theta)$$

$$(\gamma_2\text{-d}) / \sin\theta = [(\gamma_2\text{-d})^2 + (\delta + \text{d}\tan\theta)^2]^{1/2}$$

$$\gamma_2 = \text{d} + \delta\tan\theta + \text{d}\tan^2\theta$$

The effective gate opening, $G_e$:

$0 \leqq G \leqq \gamma_1$:

$$G_e = G$$

$\gamma_1 < G \leqq \gamma_2$:

$$G_e = \delta\cos\theta + G\sin\theta$$

$G > \gamma_2$:

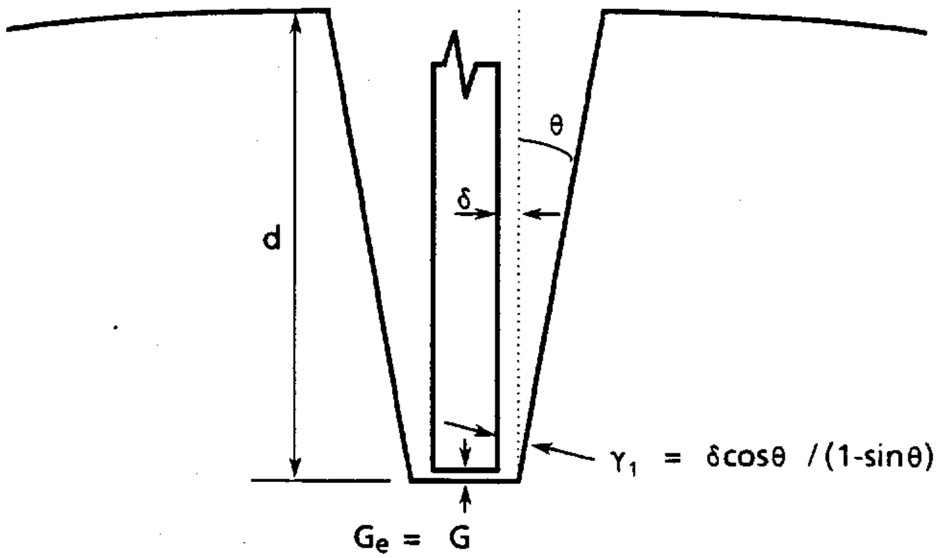
$$G_e = [(G\text{-d})^2 + (\delta + \text{d}\tan\theta)^2]^{1/2}$$

$\gamma_2$ is the value of gate opening, G, for which the distance between the gate and the slot face equals the distance between the gate and the point at which the slot meets the spillway sill (see Figure 3). That is:

$$\gamma_2 = \text{d} + \delta\tan\theta + \text{d}\tan^2\theta$$

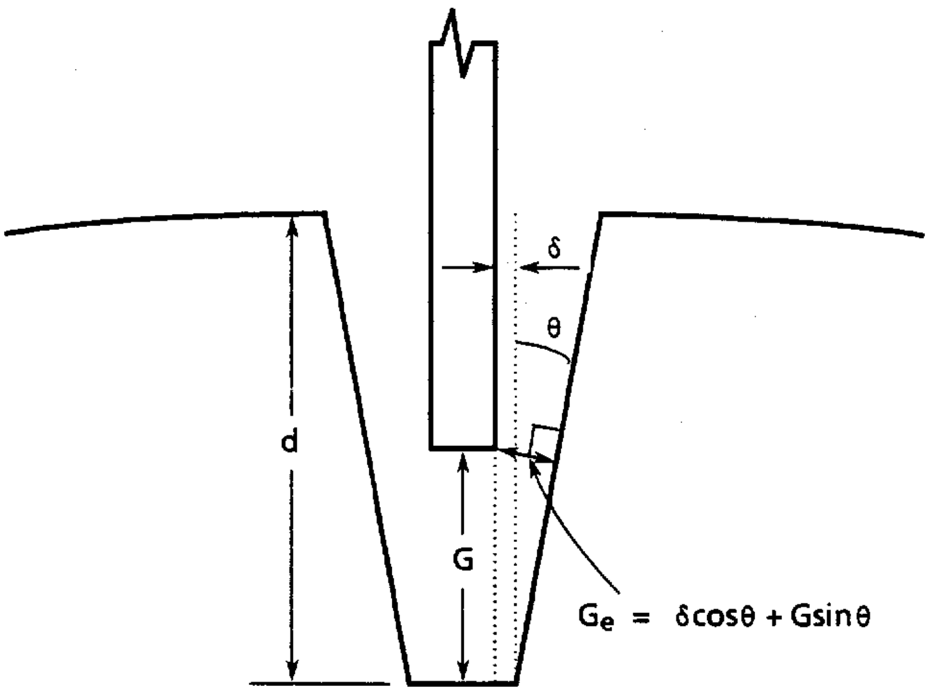
in which :

$\theta$ = angle between the slanting slot face and the original vertical face.



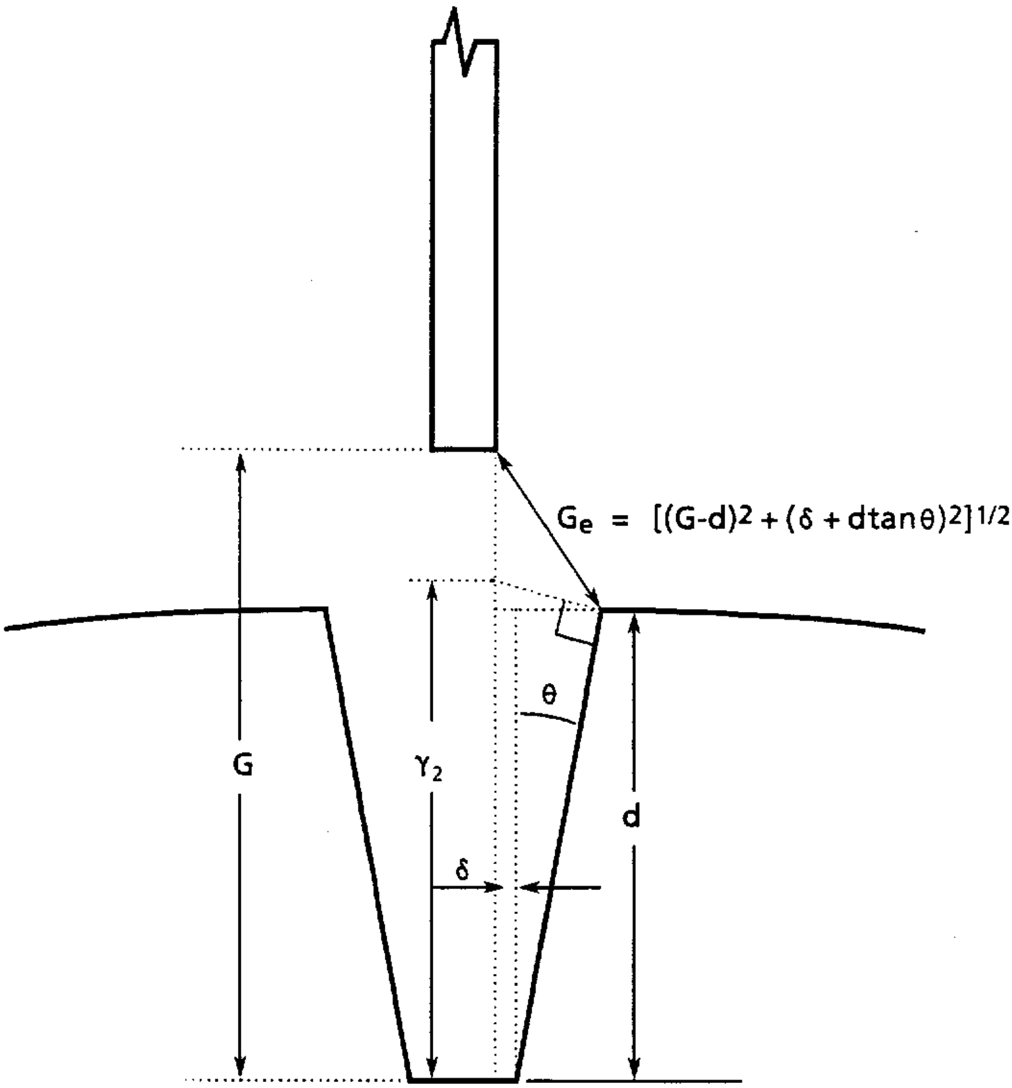

$G$ = gate opening
$G_e$ = effective gate opening
$\delta$ = gap between skin plate and assumed vertical slot face
$\theta$ = angle of deterioration (assumed symmetrical)
$d$ = depth of mudseal slot

Figure 2. Gate Opening, $G \leqq \gamma_1$




$G$ = gate opening
$G_e$ = effective gate opening
$\delta$ = gap between skin plate and assumed vertical slot face
$\theta$ = angle of deterioration (assumed symmetrical)
$d$ = depth of mudseal slot

Figure 3. Gate Opening, $\gamma_1 \leqq G \leqq \gamma_2$




G = gate opening
$G_e$ = effective gate opening
δ = gap between skin plate and assumed vertical slot face
θ = angle of deterioration (assumed symmetrical)
d = depth of mudseal slot

Figure 4. Gate Opening, $G \geqq \gamma_2$

## COMPARISON BETWEEN OLD AND NEW DISCHARGE COMPUTATIONS

The discharges through the mudseal structure before and after the assumed deterioration occurred were compared for a five-foot head across the structure and values of $\Theta$ of 0, 15, and 30 degrees. Figures 5 and 6 show this comparison for these cases at structures S-70 and S-75, respectively. Although the observed phenomenon (i.e., variable discharge in the gate opening range of 0.125 to 0.5 ft) is accounted for in the new computation method, the discharge is clearly a function of the angle $\Theta$, and depends also on the correctness of the assumed geometry. The inclination angle of 15 degrees was selected for implementation in the new discharge equations because it resulted in discharge values that produced the expected effect in the observed stages.

Verification of the proposed geometry would be difficult as it would require underwater measurements by a diver. The dangers involved preclude the possibility of these measurements. Given the circumstances, the proposed method of accounting for the observed variable discharge would appear to suffice.

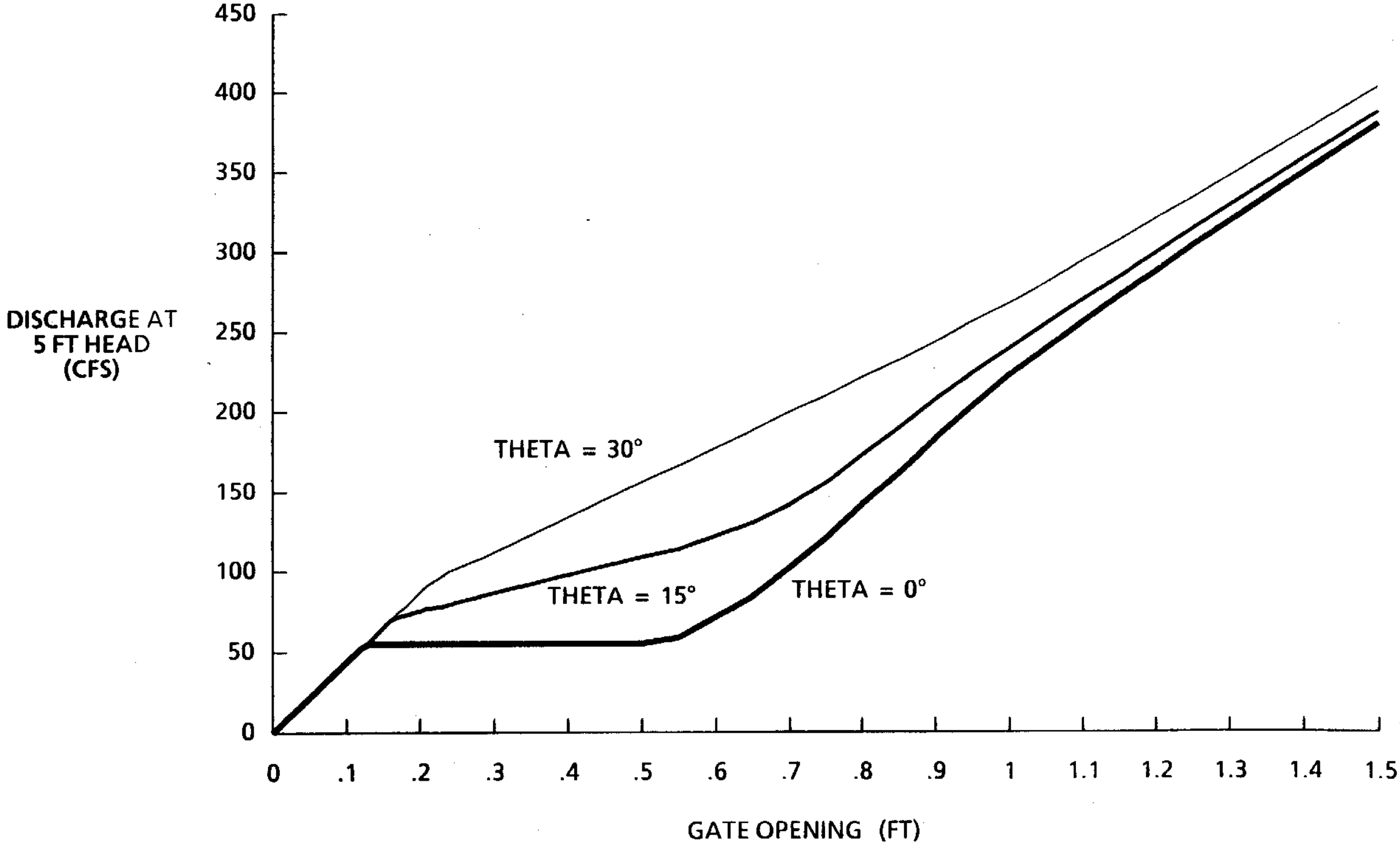



Figure 5. Effects of Mudseal Deterioration at S-70.

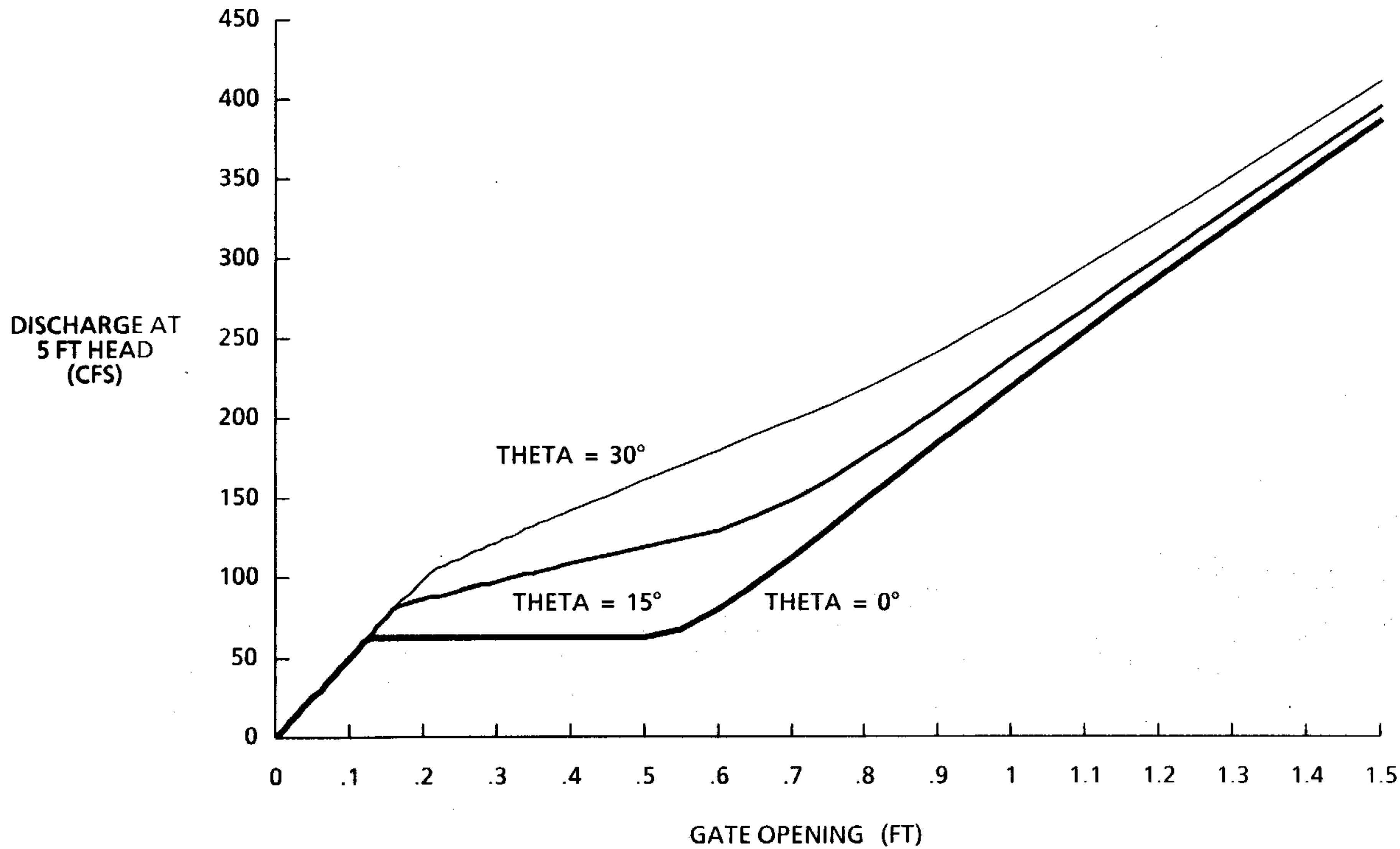



Figure 6. Effects of Mudseal Deterioration at S-75.

## CONCLUSION

The discharge through the mudseal-fitted gated structures at S-70 and S-75 control structures has been observed to increase with increasing gate opening in a range for which theory would indicate a constant discharge. To account for the variable discharge, a v-notch cross-section resulting from spalling of concrete from the originally vertical mudseal slot has been proposed. In the absence of physical verification of the current geometry of the mudseal slot, the proposed changes in the discharge equation have been implemented and adequately account for the observed behavior.

## REFERENCES

Hwa, George, Personal communication, May 1989.

# APPENDIX

# MEMORANDUM

TO: Ronald Mireau, Director, Data Management Division
Department of Resource Planning

FROM: George Hwa, Assistant Director, Operations Division GH
Department of Resource Operations

DATE: May 16, 1989

SUBJECT: Discharge Computation at S-70 and S-75

The District and the Seminole Tribe will sign a Compact Agreement to allocate water in Indian Prairie Basin. Discharge figures at S-70 and S-75 are critical parameters to execute this agreement.

Operations requests your staff to review the flow computation procedure at these two sites, especially under gate openings of less than a 0.5 foot condition, and to revise the procedure if necessary.

Thank you.

GH/rb

c: J. Marban
R. Slyfield
✓ B. Turcotte

RECEIVED

MAY 17 1989

DATA MANAGEMENT